CELEBRATION 2000 SEISMIC EXPERIMENT

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1. INTRODUCTION

Building on the experience gained and collaborations formed during the very successful POLONAISE'97 experiment (*Guterch et al., 1999*) that provided 3-D images of crustal structure (*Środa et al., 2002*) and 2-D models of the lithospheric mantle (*Grad et al., 2002*), an even more ambitious project was organized to target the intricate collection of major tectonic features in the Trans-European Suture Zone (TESZ) region, the southwestern portion of the East European craton (southern Baltica), the Carpathian Mountains, the Pannonian basin, and the Bohemian massif (*Bogdanova et al., 2001*; *EUROBRIDGE Working Group, 1999*; *Keller and Hatcher, 1999*; *Linzer et al., 1998*; *Posgay et al., 1995*; *Thybo et al., 1999, 2002*). This experiment named CELEBRATION 2000 (**C**entral **E**uropean **L**ithospheric **E**xperiment **B**ased on **R**efraction, **2000**) was a huge international cooperative effort that involved 28 institutions from Europe and North America. The massive data set produced by this experiment is providing a 3-D picture of the crust and upper mantle that will help to answer many of the questions that remain about the structure and tectonic evolution of this interesting region (*Guterch et al., 2001*). However, providing a technical description of this experiment is purpose of this paper. Other recent Central Europe seismic experiments are described in papers by *Guterch et al. (2003)*, *Brueckl et al. (2003)*, *Grad et al. (2003)* and *Plomerová et al. (2003)*.

2. DESCRIPTION OF THE PROJECT

The fieldwork for CELEBRATION 2000 consisted of three overlapping deployments of 1230 instruments that formed a large array that migrated southward during these deployments. The moving recording array formed a network of interlocking profiles (Figure 1) whose total length was about 8900 km, and the station spacing along the profiles was 2.8 or 5.6 km. The layout of the sources and receivers provided 5400 km of traditional profile data in addition to the array.

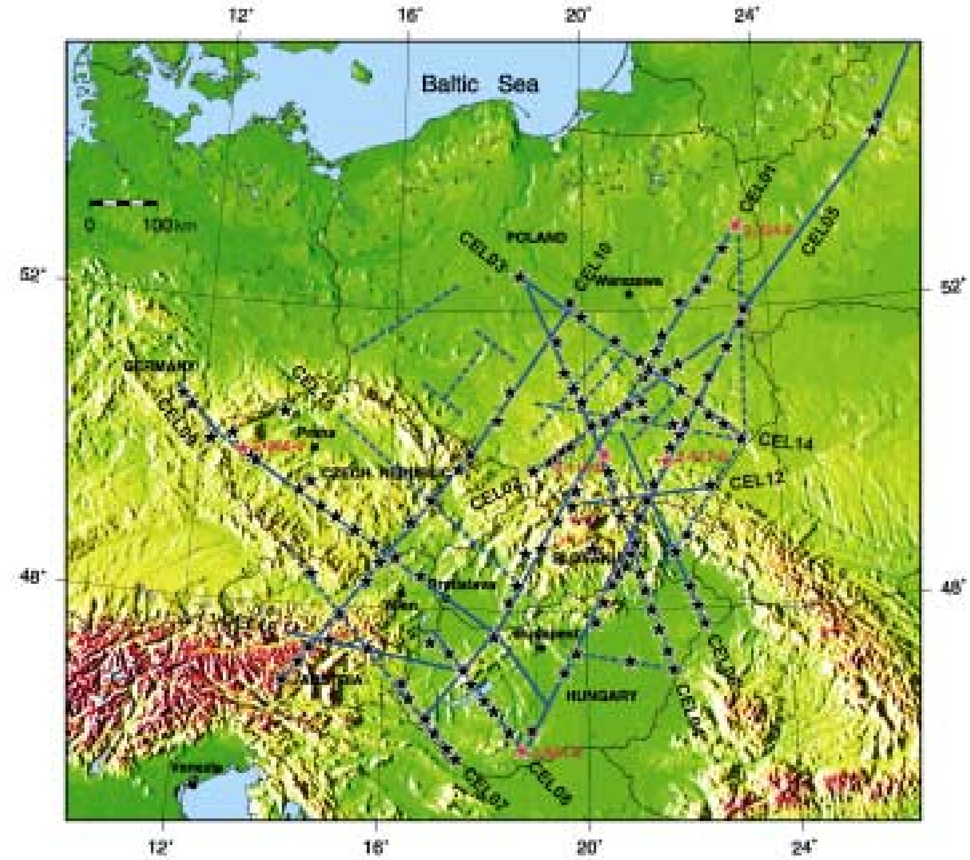

Fig. 1. Index map showing profile lines and shot points of the CELEBRATION 2000 seismic experiment. The red stars show the seismic sources that produced the record sections shown in Figure 2.

Table 1. Details of the explosive sources used in the *CELEBRATION 2000* experiment.

Shot number	Latitude N	Longitude E	Elevat. (m)	Date yyyy.mm.dd	Time UTC hh:mm:ss	Time correction
20010	46°58.235 '	14°01.817 '	1500	2000.06.24	02:30:00.441	0
20020	47°12.959 '	14°19.501 '	1410	2000.06.24	02:45:03.070	0
20030	47°25.573 '	14°30.888 '	1448	2000.06.24	03:00:02.327	0
20040	47°53.025 '	15°05.711 '	1035	2000.06.25	02:15:00.458	0
20050	48°20.424 '	15°35.706 '	420	2000.06.25	03:44:59.730	0
20060	48°36.199 '	15°50.684 '	350	2000.06.25	03:00:00.223	0
20070	49°08.696 '	16°26.286 '	320	2000.06.23	21:00:12.320	0
20080	49°26.788 '	16°49.942 '	619	2000.06.23	23:15:00.000	0
20081	49°26.788 '	16°49.964 '	619	2000.06.24	00:15:00.000	0
20090	49°52.331 '	17°23.365 '	660	2000.06.24	01:00:00.000	0
20091	49°52.314 '	17°23.355 '	661	2000.06.24	01:15:00.000	0
20092	49°52.297 '	17°23.346 '	662	2000.06.16	22:15:00.000	0
20100	50°04.544 '	17°37.479 '	428	2000.06.23	22:45:00.000	0
20110	50°31.990 '	18°10.610 '	222	2000.06.23	23:00:00.000	0
20120	50°54.999 '	18°26.757 '	243	2000.06.24	23:00:00.000	0
21010	46°31.596 '	16°51.168 '	240	2000.06.14	22:00:00.000	-0.23
21011	46°31.596 '	16°51.168 '	240	2000.06.23	22:15:00.000	-0.07
21020	47°11.059 '	17°33.860 '	310	2000.06.24	00:00:00.000	0
21030	47°37.764 '	18°09.249 '	130	2000.06.14	21:45:00.000	0
21031	47°37.764 '	18°09.249 '	130	2000.06.23	22:30:00.000	0
21060	48°05.567 '	18°26.703 '	265	2000.06.15	22:45:00.000	0
21070	48°19.173 '	18°36.483 '	349	2000.06.15	22:30:00.000	-2
21080	48°49.372 '	19°05.360 '	676	2000.06.15	01:30:00.000	0
21090	48°45.382 '	18°46.348 '	550	2000.06.15	02:30:00.000	0
21100	49°11.512 '	19°25.723 '	855	2000.06.14	22:30:00.000	-1.3
21110	49°23.384 '	19°43.487 '	705	2000.06.08	23:00:00.000	0
21120	49°36.142 '	19°48.500 '	640	2000.06.14	23:00:00.000	0
21130	50°05.078 '	20°23.994 '	186	2000.06.16	00:30:00.000	0
21140	50°37.577 '	20°40.650 '	258	2000.06.10	01:00:00.000	0
21150	50°43.667 '	20°55.000 '	265	2000.06.10	00:30:00.000	0
21160	51°06.439 '	21°16.577 '	203	2000.06.08	00:45:00.000	0
21170	51°12.613 '	21°22.598 '	184	2000.06.14	23:45:00.000	0
21180	51°25.747 '	21°32.990 '	169	2000.06.09	00:45:00.000	0
21190	51°39.059 '	21°41.681 '	119	2000.06.10	00:45:00.000	0
21200	52°05.636 '	22°05.494 '	176	2000.06.09	23:00:00.000	0
21210	52°14.522 '	22°29.509 '	178	2000.06.07	23:45:00.000	0
21220	52°22.918 '	22°41.499 '	117	2000.06.08	23:15:00.000	0
21230	52°46.450 '	23°04.803 '	153	2000.06.07	23:15:00.000	0
21240	53°04.788 '	23°24.599 '	164	2000.06.08	01:15:00.000	0
22020	49°51.756 '	18°55.700 '	280	2000.06.16	01:00:00.000	0
22030	49°58.817 '	19°16.454 '	260	2000.06.16	23:00:00.000	0
22040	50°02.700 '	19°25.077 '	225	2000.06.17	00:30:00.000	0
22050	50°07.350 '	19°32.458 '	295	2000.06.16	23:30:00.000	0
22060	50°11.389 '	19°41.880 '	442	2000.06.17	00:00:00.000	0
22100	50°30.717 '	20°25.429 '	244	2000.06.15	23:00:00.000	0
22130	50°46.378 '	21°12.776 '	309	2000.06.15	00:00:00.000	0

22150	51°10.066 '	21°44.426 '	156	2000.06.15	23:45:00.000	0
22160	51°15.487 '	22°00.200 '	223	2000.06.16	23:45:00.000	0
23010	52°27.850 '	18°37.697 '	106	2000.06.17	00:45:00.000	0
23020	52°07.165 '	19°42.967 '	102	2000.06.15	00:45:00.000	0
23030	51°55.145 '	19°57.115 '	190	2000.06.17	00:15:00.000	0
23050	51°35.894 '	20°41.002 '	131	2000.06.15	00:15:00.000	0
23070	51°19.480 '	21°12.119 '	179	2000.06.16	00:15:00.000	0
23100	50°54.689 '	22°02.208 '	215	2000.06.16	23:15:00.000	0
23120	50°33.627 '	22°36.819 '	216	2000.06.15	23:15:00.000	0
23130	50°25.866 '	22°55.218 '	195	2000.06.14	23:15:00.000	0
23140	50°13.101 '	23°15.648 '	245	2000.06.08	00:30:00.000	0
24010	51°35.475 '	19°25.153 '	225	2000.06.15	01:15:00.000	0
24020	51°10.550 '	19°35.060 '	230	2000.06.17	01:00:00.000	0
24021	51°10.550 '	19°35.060 '	230	2000.06.17	01:30:00.000	0
24030	50°57.472 '	19°46.671 '	225	2000.06.15	00:30:00.000	0
24040	50°46.519 '	19°56.748 '	260	2000.06.15	23:30:00.000	0
24050	50°28.363 '	20°09.230 '	328	2000.06.16	00:00:00.000	0
24070	49°50.712 '	20°28.326 '	398	2000.06.09	23:00:00.000	0
24080	49°26.669 '	20°36.445 '	1123	2000.06.07	23:00:00.000	0
24090	49°13.843 '	20°43.200 '	762	2000.06.09	22:30:00.000	0.51
24120	48°28.644 '	21°04.807 '	280	2000.06.08	21:15:00.000	-0.218
24130	48°14.999 '	21°10.094 '	124	2000.06.09	01:30:00.000	-0.275
24140	47°59.845 '	21°17.203 '	94	2000.06.09	21:30:00.000	-0.477
24150	47°43.210 '	21°25.481 '	98	2000.06.07	21:45:00.000	0
24160	47°25.820 '	21°34.529 '	102	2000.06.08	02:00:00.000	0
24170	47°10.581 '	21°41.029 '	96	2000.06.07	22:00:00.000	0
25010	46°06.819 '	18°42.486 '	110	2000.06.25	21:15:00.000	0
25020	46°23.277 '	18°54.814 '	90	2000.06.25	22:15:00.000	0
25040	47°09.340 '	19°32.480 '	140	2000.06.24	21:30:00.000	0
25050	47°24.991 '	19°46.992 '	101	2000.06.07	21:15:00.000	0
25070	47°50.033 '	20°10.386 '	145	2000.06.08	01:30:00.000	0
25080	48°05.836 '	20°20.119 '	330	2000.06.07	21:30:00.000	0
25090	48°20.252 '	20°30.842 '	270	2000.06.08	21:45:00.000	0
25100	48°28.840 '	20°38.875 '	272	2000.06.08	21:30:00.000	0
25110	48°45.160 '	20°53.807 '	609	2000.06.08	22:30:00.000	0.578
25120	48°52.972 '	20°59.827 '	480	2000.06.10	01:30:00.800	0.796
25130	49°13.653 '	21°04.972 '	686	2000.06.09	22:45:00.000	0.255
25140	49°27.668 '	21°15.493 '	601	2000.06.07	23:30:00.000	0
25150	49°40.168 '	21°24.628 '	291	2000.06.08	01:00:00.000	0
25170	49°58.248 '	21°40.881 '	360	2000.06.08	23:30:00.000	0
25180	50°09.055 '	21°46.659 '	222	2000.06.09	00:00:00.000	0
25190	50°19.350 '	21°59.650 '	196	2000.06.09	00:30:00.000	0
25200	50°28.395 '	22°06.888 '	168	2000.06.09	01:00:00.000	0
25210	50°44.858 '	22°24.231 '	257	2000.06.10	00:15:00.000	0
25220	51°04.549 '	22°38.794 '	248	2000.06.09	00:15:00.000	0
25230	51°27.748 '	23°03.876 '	169	2000.06.08	00:15:00.000	0
25240	51°45.698 '	23°22.981 '	159	2000.06.09	23:45:00.000	0
25250	51°57.718 '	23°28.332 '	144	2000.06.08	23:45:00.000	0
25270	54°11.301 '	26°39.142 '	180	2000.06.07	21:00:00.000	0
25280	54°23.888 '	26°49.758 '	154	2000.06.08	21:00:00.000	0
25290	56°54.450 '	29°18.650 '	198	2000.06.10	01:15:01.000	0

26120	48°58.820 '	22°03.417 '	252	2000.06.07	22:30:00.000	2.0
26140	49°37.391 '	22°34.732 '	390	2000.06.08	00:00:00.000	0
26200	50°32.932 '	21°15.593 '	217	2000.06.10	00:00:00.000	0
26210	50°27.472 '	21°51.624 '	187	2000.06.09	23:30:00.000	0
26220	50°27.526 '	21°51.625 '	187	2000.06.25	23:00:00.000	0
26221	50°27.511 '	21°51.456 '	187	2000.06.25	23:30:00.000	0
26640	48°45.237 '	21°48.468 '	225	2000.06.07	22:45:00.000	5.5
26650	48°17.073 '	22°04.126 '	99	2000.06.09	22:15:00.000	0
26660	48°01.904 '	22°12.550 '	140	2000.06.09	21:00:00.000	0
26670	47°47.207 '	22°20.002 '	125	2000.06.09	21:15:00.000	0
26700	47°18.236 '	20°50.091 '	87	2000.06.07	22:15:00.000	0
26710	48°34.833 '	20°48.310 '	300	2000.06.08	22:45:00.000	0.321
26720	48°49.060 '	20°08.025 '	900	2000.06.09	02:00:00.000	0
26800	47°31.920 '	14°54.755 '	1140	2000.06.24	03:29:58.824	0
26801	47°31.920 '	14°54.755 '	1140	2000.06.26	02:59:59.035	0
26810	47°26.623 '	15°40.698 '	942	2000.06.24	02:14:59.687	0
26900	50°33.778 '	13°43.462 '	220	2000.06.24	03:15:00.735	0
26901	50°33.788 '	13°43.510 '	220	2000.06.24	03:45:01.295	0
26910	50°13.001 '	12°40.098 '	399	2000.06.25	03:15:00.113	0
26911	50°13.035 '	12°40.066 '	399	2000.06.25	03:29:59.895	0
27010	48°24.439 '	14°28.866 '	620	2000.06.25	02:45:00.443	0
27020	46°59.592 '	16°22.209 '	232	2000.06.24	00:30:00.000	0
27030	46°47.146 '	16°30.321 '	230	2000.06.23	21:15:00.000	0
27050	46°19.829 '	17°01.922 '	220	2000.06.24	01:30:00.000	-0.1
27060	46°07.840'	17°16.374 '	140	2000.06.24	21:15:00.000	0
27070	45°59.308 '	17°26.859 '	120	2000.06.25	00:00:00.000	0
28030	47°33.019 '	16°54.288 '	150	2000.06.24	00:45:00.000	0
28040	47°24.163 '	17°17.015 '	128	2000.06.23	21:30:00.000	0
28060	46°59.825 '	17°43.165 '	245	2000.06.23	21:45:00.000	0
28070	46°46.781 '	17°59.113 '	168	2000.06.25	21:45:00.000	0
28080	46°38.329 '	18°10.370 '	130	2000.06.25	21:30:00.000	2.97
28090	46°20.966 '	18°28.782 '	142	2000.06.24	21:45:00.000	-0.25
29010	50°41.250 '	11°33.438 '	270	2000.06.23	19:31:12.417	0
29020	50°32.664 '	11°45.996 '	526	2000.06.23	19:14:30.133	0
29040	50°07.274 '	12°13.505 '	630	2000.06.23	19:00:30.767	0
29050	50°01.249 '	12°54.537 '	680	2000.06.26	00:45:00.000	0
29051	50°01.263 '	12°54.548 '	679	2000.06.26	00:15:00.000	0
29060	49°55.506 '	13°05.540 '	661	2000.06.26	01:00:00.000	0
29061	49°55.499 '	13°05.554 '	661	2000.06.26	01:15:00.000	0
29070	49°52.353 '	13°11.958 '	545	2000.06.26	03:48:05.896	0
29080	49°38.719 '	14°20.946 '	446	2000.06.26	03:15:00.805	0
29090	49°31.094 '	14°07.771 '	474	2000.06.24	22:00:00.000	0
29100	49°18.749 '	14°35.405 '	476	2000.06.24	21:00:00.000	0
29110	49°11.354 '	14°54.629 '	492	2000.06.25	00:15:00.000	0
29111	49°11.381 '	14°54.631 '	492	2000.06.25	00:45:00.000	0
29120	49°01.150 '	15°19.038 '	612	2000.06.24	22:45:00.000	0
29121	49°01.150 '	15°19.008 '	615	2000.06.24	23:15:00.000	0
29130	48°51.156 '	15°41.985 '	459	2000.06.26	02:14:59.997	0
29140	48°40.338 '	16°09.384 '	417	2000.06.26	02:30:00.396	0
29150	48°26.201 '	16°40.395 '	232	2000.06.26	02:45:00.957	0

2.1 Shooting Procedures

Scientific organizations in Poland, Hungary, the Czech Republic, the Slovak Republic, Austria, Russia, Belarus and Germany provided the sources in their countries and the distribution is shown in Figure 1. The size of the sources ranged from 15 metric tons in Russia to 90 kg and averaged ~ 500 kg. Some of the sources were relatively small and could not be recorded by all of the receivers, but we estimate that ~ 100,000 usable seismograms were obtained. Details of shot point location and shooting times for all 147 shots are listed in Table 1.

2.2 Instruments

About 840 of the 1230 instruments were the RefTek 125 ('Texan') recorders, with 640 of these being from the *PASSCAL/UTEP* pool. This instrument was developed as a partnership between the University of Texas at El Paso (*UTEP*) and RefTek, Inc. initially with funding from the State of Texas. This development effort involved input from many members of the seismological community and significant cooperation with *IRIS/PASSCAL*. An annual grant from *IRIS/PASSCAL* helps maintain the portion of these instruments.

Rapidly advancing digital technology has made it possible to greatly reduce the weight, size, and power consumption of seismic instruments while increasing their functionality and reliability. The final design of the 'Texan' instrument considered many factors. In particular, two factors greatly affect the cost of seismic data acquisition. The first is the amount of labor required to layout and pickup seismic cables, geophones and recording equipment. The second is the amount of time spent recording data, particularly from vibrator sources. The 'Texan' instrument eliminates seismic cables and greatly reduces the weight of the recording instrument. This new instrument has also adequate memory to record continuously for 6 or more hours at a 2 ms sampling interval and a high precision clock so that the data are still accurately timed.

Specifically, the 'Texan' instrument meets the following key specifications:

1. Lightweight (less than 1.4 kg), single channel. This is a small fraction of the typical weight of combined cables, batteries, and recorders for the units used in the past.
2. Low power consumption (150 mW in recording mode, 25 mW in sleep mode). The instrument will operate for days on 2 D-cell batteries. After over 20 experiments, experience has shown that the instruments can be operated reliably for 8 days in most circumstances
3. An analogue to digital converter with 24-bit dynamic range. This high-quality converter enables the extraction of low amplitude signals in the presence of high amplitude signals, a common occurrence with vibrator sources.
4. High precision timing (0.1 ppm accuracy temperature-compensated crystal oscillator). This high-precision time standard allows for many hours of recording while maintaining accurate time. After over 20 major experiments, our experience is that the clock drift rate is 5-7 milliseconds per day. Time resulting from the clock drift is corrected during pre-processing of the data.

5. High reliability electronics. All electronics is solid state, except for geophone, with relatively few chips and no communications cables. The electronics remain sealed except for battery changes to minimize exposure to moisture and dirt.
6. Relatively large recording capacity. The memory that was initially the standard (32 Mbyte) provides at least 32 hours of continuous recording at a sample interval of 10 ms (100 samples per second).
7. Automatic pre- and post-deployment quality control. The programming and quality control system was designed so that instrument failures in the field would be minimal and thus no field repair capability is needed. The deployers only check to see if the indicator light reads green, which it does about 99% of the time. A red light simply indicates that the instrument should not be deployed. Thus, the crew only needs only minimal knowledge of the instrument and spends virtually no time in the field worrying about the readiness of the instrument to record.

The total of 840 ‘Texan’ instruments available for CELEBRATION 2000 were as follows: Austria – 15, Denmark – 100, Finland – 10, Poland – 15, Turkey – 60, USA – 640.

They were programmed with a window and several reserve windows for each shot. In most cases, the recording time in each window was 4 min 50 s, but there were also a few extended windows up to 8 min in length. For the shot windows, the sample rate was 100 Hz (10 ms), and for the extended windows it was 50 Hz (20 ms).

An additional 50, 3-complonent instruments from the *IRIS/PASSCAL* pool were deployed in the Czech Republic and 20 3-component recorders were deployed in Poland for about a month to record continously both the shots and earthquakes. These instruments were as follows: MK-4P – 20 recording units (made in Poland) and RefTek 72A – 50 recording units, all using Mark Products L-4-3D / 1 Hz seismometers.

2.3 Data Processing

The size of the CELERATION 2000 data set somewhat overwhelmed the ‘Texan’ data processing system of the time, this fact helped lead to improvements that made the processing easier for ALP 2002 and SUDETES 2003. There was also a significant amount of data from other types of instruments that made merging the data sets into a seamless master data set complex. Although we were able to view the various data sets, processing of the raw data into SEGY traces was not completed until November of 2000. This was largely due to complications with legacy software designed to accommodate much smaller data sets. All raw data from the Texan-recordings are saved on several hard disks and tapes. The raw data of all shots and from the ‘Texan recorders’ were converted to SEGY, completed by adding geometry information and saved on CD-ROM. They were ready for distribution and interpretation (ZPOLT, ProMAX, SEIS83, FAST, etc.) within a six months of the experiment. Samples of recordings, demonstrating the quality of the data are shown on Figure 2.

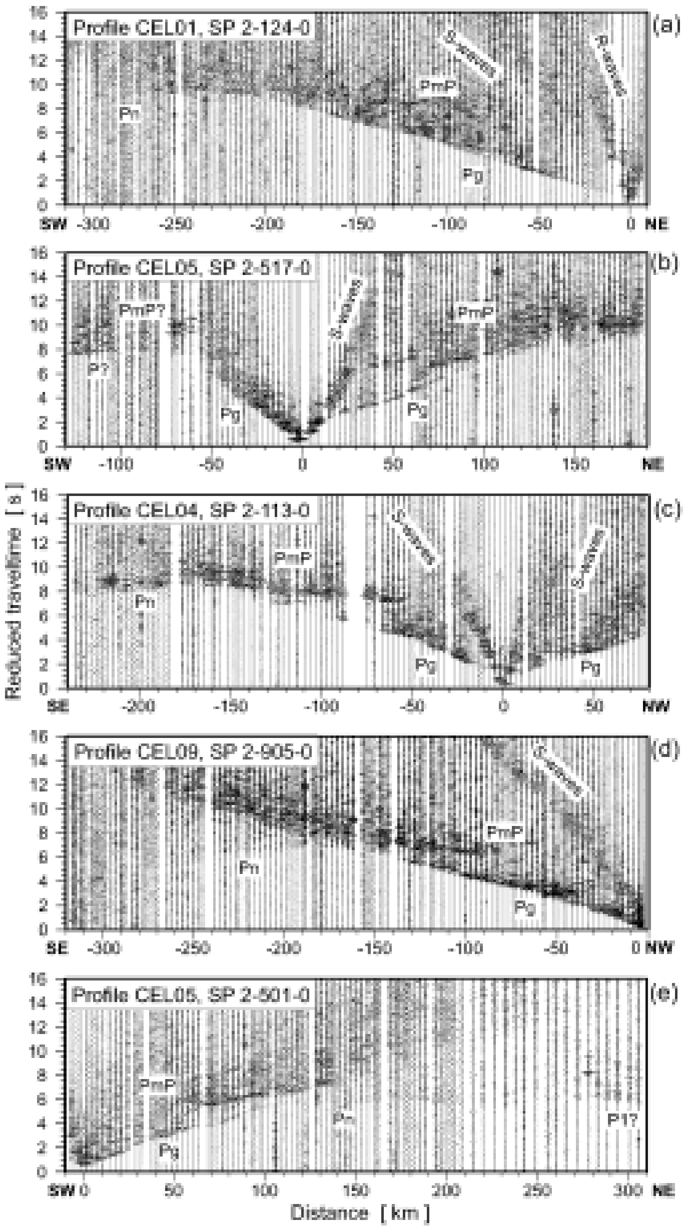

Fig. 2. Record sections from different tectonic regimes: (a) East European craton; (b) Polish trough/TESZ; (c) Carpathian Mountains; (d) Bohemian massif; (e) Pannonian basin. All record sections are displayed with a reducing velocity of 8.0 km/s so that refracted arrivals from the uppermost mantle (Pn) are nearly horizontal. PmP is the P-wave reflected from the upper mantle. Pg is the diving wave traveling in the upper and middle crust. P1 indicates a mantle reflector.

3. INITIAL RESULTS

During CELEBRATION 2000, the seismic recorders worked well (~95% data recovery) and the efficiency of the seismic sources was also very good except in very few cases. Processing and initial analysis of the massive data set produced is complete and interpretation of individual record sections is well underway.

A detailed system of seismic measurements along the 1400 km long profile CEL05 provided key information to determine detailes of lithospheric structure of the East European Craton, TESZ (including the Holy Cross Mountains and Małopolska block), Carpathians and Pannonian basin. The crustal thickness beneath profile CEL05 changes from 43 – 50 km beneath East European Craton to about 30 – 40 km beneath the Palaeozoic Platform and Carpathians, and to only 24 – 28 km beneath the Pannonian basin. The depth of the consolidated basement with velocity Vp = 6.0 km/s changes from 1 – 3 km on the East European Craton to about 5 – 8 km beneath Pannonian basin, reaching up to 10 – 18 km in TESZ and Carpathians. The East European Craton has a typical thick, three-layer structure for the crystalline crust (with velocities 6.1 – 6.4, 6.5 – 6.6 and 6.8 – 6.9 km/s, respectively), while in the Carpathian-Pannonian area thin crust is characterized by relatively low Vp velocities (6.1 – 6.4 km/s in the upper crust and 6.4 – 6.6 km/s in the lower crust). The velocity in the uppermost mantle is 8.1 – 8.25 km/s beneath East European Craton and 7.8 – 8.0 km/s beneath Carpathian-Pannonian area.

An example of the crustal structure modelling for CELEBRATION 2000 profile CEL05 using tomographic approache for the first arrival traveltimes (*Hole, 1992*) is shown in Figure 3. The strong asymmetry of the deep basin in the area of TESZ and Carpathians is well visible. The Moho may be represented by the velocity isoline, which is an average for the lowermost crust and uppermost mantle. It corresepons to velocity ~ 7.4 km/s in the Pannonian basin and ~ 7.5 km/s for the East European Craton.

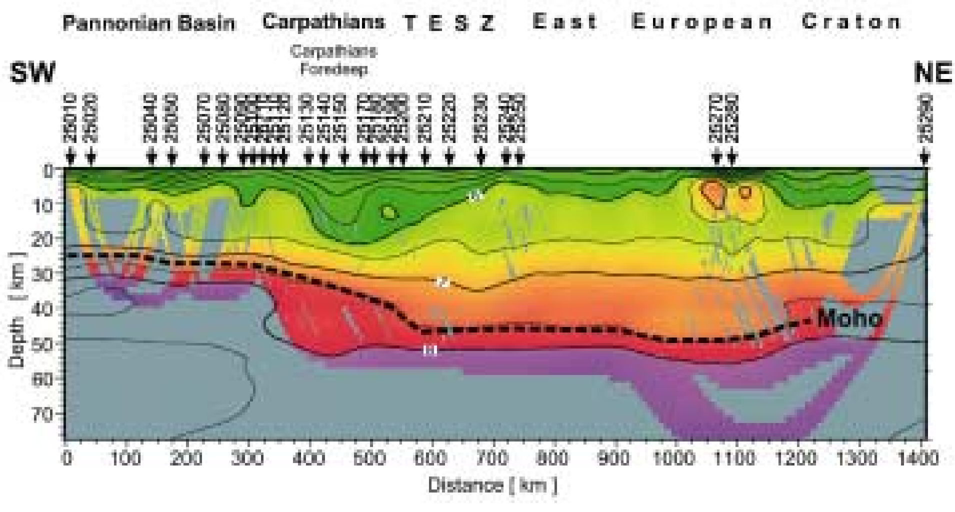

Fig. 3. Crustal model for CELEBRATION 2000 profile CEL05 using tomographic approach for the first arrival traveltimes (*Hole, 1992*).

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